

Municipal scale scenario: Analysis of an Italian seaside town with MarkAL-TIMES

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ARTICLE INFO

Article history:

Received 15 November 2010

Accepted 27 October 2011

Available online 1 December 2011

Keywords:

Local energy planning

Micro-chp

Energy efficiency

ABSTRACT

This work presents three 25-year energy scenarios developed with the TIMES model generator for Pesaro, a seaside municipality in central Italy. It evaluates the effectiveness of local-scale energy policies in three sectors: households, transport, and the public sector (PS). Since the local energy demand is affected by summer tourism, seasonal consumption by holiday homes was also studied. Three scenarios were hypothesized: Business as Usual (BAU), Exemplary Public Sector (EPS), and Exemplary Municipality (EM). The EPS scenario models the exemplary role that recent European directives attribute to the PS in setting energy efficiency and technology penetration targets for itself; the EM scenario extends these targets to the household sector. In particular, the study underscores the potential of micro-cogeneration technologies in achieving local environmental targets, even though their diffusion would involve an increase in local energy consumption due to internalization of the primary energy used to produce electricity, which would no longer be wholly imported from outside municipal boundaries. The study provides information to local decision-makers by estimating the cost of implementing a number of energy policies. Finally, the study discusses the adequacy of TIMES as a tool to analyse municipal-scale scenarios.

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1. Introduction

National as well as larger-scale environmental targets can be achieved using both a top-down and a bottom-up approach (IPCC, 2007; Dilly and Hüttel, 2009). The former approach defines a regulatory framework where policy goals are set for the short, medium, and long term. For instance, European energy policies originate in the European Commission and Parliament as Directives, which must then be adopted by member States (European Parliament and Council, 2004, 2009a,b,c). Once the regulatory framework is in place, the bottom-up approach is applied on a local scale through implementation of best practices and policies (UN Department of Economic and Social Affairs, 2002). Here municipal energy plans play an important role in refining and adapting the energy policies to the local context, taking advantage of local administrators' thorough knowledge of the territory in terms of resources as well as economic structure (IEA, 2000; Stenlund Nilsson and Mårtensson, 2003; Ivner, 2009; Sperling et al., 2011). Clearly, energy planning would also greatly benefit from investigations into the connections of Energy-Economy-

Engineering-Environment (Barker et al., 2005). The Italian legislation (Italian Parliament, 1991) requires each Region to draw up a Regional Environmental and Energy Plan (REEP) to improve energy efficiency and develop renewable sources. Article 5 of the recent European Directive 2006/32/EC (European Parliament and Council, 2006) attributes to the public sector (PS) an exemplary role in implementing and promoting good energy practices. The REEP of Marche (Marche Region Parliament, 2005), an Adriatic region in central Italy, sets targets for energy efficiency and energy production from renewable sources, providing financial support for the draughting of a Municipal Environmental and Energy Plan (MEEP) by towns with more than 50 000 inhabitants.

The present work, which is part of the MEEP of Pesaro (Pesaro Municipality, 2008), a coastal town of Marche with more than 90 000 inhabitants, describes three medium- to long-term (up to 2030) energy scenarios developed for the city. The study was carried out using the TIMES model generator (ETSAP; Loulou et al., 2005). Analysis of the energy scenario on the municipal scale is an unusual application of the MarkAL and MarkAL-TIMES models, which are commonly applied to (i) evaluate national-level energy scenarios, policies and incentives mechanisms (Farinelli et al., 2005; Contaldi et al., 2007; Blesl et al., 2007; Cosmi et al., 2009; Assoumou and Maïzi, 2011); (ii) assess the impacts of technologies in a nation-wide context (Naughten, 2003; Nguyen, 2007; Rafaj and Kypreos, 2007; Vaillancourt

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et al., 2008), and (iii) project energy demand trends (Dutta and Mukherjee, 2010; Jia et al., 2011). Regional and municipal scenarios have already been developed with MarkAL, but not with TIMES; for instance, Salvia et al. (2004) and Pietrapertosa et al. (2003) have published region-based studies, whereas Cosmi et al. (2003) have analysed on the municipal scale the feasibility of introducing renewable technologies in an urban area. The present study is different in that it examines on the municipal scale the amount and type of energy consumed by municipal PS users, by households and by the transport sector with a view to identifying the role of energy efficiency in curbing primary energy consumption. The paper is organized as follows: after Section 1, Section 2 outlines the local energy system; Section 3 describes the demand by the different sectors and the scenario assumptions; and Section 4 presents the results analysis; finally, in Section 5 the results are discussed and commented on; in particular, given the uncommon application of the TIMES in this study, the pros and cons of using it on such a small scale are discussed in a separate paragraph.

2. The local energy system

Pesaro, one of the five provincial capitals of Marche (east-central Italy), is a coastal town with a population > 90 000, which summer tourism swells by about 11% (Pesaro Municipality, 2005). According to Marche's REEP, Pesaro lies in the Region's most energy-intensive district. Nevertheless, no energy is produced in the territory of Pesaro, apart from a negligible fraction from renewable sources, mainly photovoltaic (PV). For this reason, nearly all the primary energy used to meet the local demand for heat and electricity is imported from outside the municipality. Since the year for which the energy demand and supply data of the municipal energy balance (MEB) are most abundant was 2004, 2004 was chosen as the base year for model calibration. The consumption of energy commodities in 2004 is indicated in Table 1.

Table 2 reports the consumption of electrical and thermal energy commodities divided by sector.

Table 3 reports the fuel consumption related to municipal transport, a major local user.

According to the "Urban mobility plan" (Pesaro Municipality, 2003), consumption by public transport means accounts for < 1% of total fuel consumption by the transport sector.

Table 1
MEB in 2004.

Commodity	(GJ)	Per cent consumption in base year (%)
Electricity	1 543 241	24
Vehicle fuel	1 937 107	31
Natural gas	2 818 602	45
TOTAL	6 298 950	100

Table 2
Share of electrical energy and natural gas consumed by the main users in 2004.

Sector	Electricity (GJ)	Per cent of total electrical energy consumed (%)	Natural gas (GJ)	Per cent of total thermal energy consumed (%)	Total (GJ)	Per cent of total energy consumed (%)
Agriculture	4630	0.3	0	0.0	4630	0.1
Households	429 021	27.8	1 203 543	42.7	1 632 564	37.4
Industry	526 245	34.1	1 288 101	45.7	1 814 346	41.6
Services	583 345	37.8	326 958	11.6	910 303	20.9
TOTAL	1 543 241	100.0	2 818 602	100.0	4 361 843	100.0

Since the present study was carried out in collaboration with Pesaro municipality, the thermal and electrical energy consumed by municipal users was analysed in detail (Table 4).

As regards energy production, PV and solar thermal plants were the sole renewable technologies used in the area. The total PV power installed in 2004, predominantly by private users, was a mere 350 kW_e. Assuming an electricity production of 1250 kWh_e per nominal kW installed, these plants accounted for just 0.1% of the electricity consumed in 2004. Table 5 reports the trend of the nominal PV power installed in the municipality (GSE, 2011) and an estimate of the electrical energy produced. An increase in installed PV power after 2004 is quite common in Italy, due to the launch in 2005 of the feed-in tariff, an incentive known in Italy as "Conto Energia". The table shows separately the PV

Table 3

Share of fuel consumed by the municipal transport sector, in 2004.

Fuel	2004 (GJ)	Per cent of fuel consumed (%)
Diesel fuel	796 471	40.7
Lpg	33 245	1.7
Unleaded petrol	1 107 392	56.6
Natural gas	19 170	1.0
TOTAL	1 956 278	100.0

Table 4

Energy consumed by municipal users in 2004.

	Thermal energy (GJ)	Electrical energy (GJ)	Total energy (GJ)
Street lighting	–	25 881	25 881
Traffic lights and cemeteries	–	1537	1537
Schools	30 206	4168	34 374
Municipal offices	8486	4752	13 238
Other uses	9254	10 555	19 809

Table 5

Trend of installed PV power and energy produced in Pesaro municipality.

	< 20 kWp		All sizes	
	Installed (kWp)	Energy produced (TJ)	Installed (kWp)	Energy produced (TJ)
2008	111.1	0.5	534.5	2.4
2009	170.9	0.8	170.9	0.8
2010	398.8	1.8	3821.2	17.2
2011 ^a	311.0	1.4	3067.2	13.8
Total	991.8	4.5	7593.8	34.2

^a Provisional (August 2011).

plants < 20 kWp, which is the typical size of household and PS plants. The energy produced by solar thermal panels is negligible, being estimated by the MEEP at just 0.05% of the municipal demand for thermal energy based on total area installed (private sector = 711 m²; PS = 60 m²). Pesaro municipality is currently assessing the option of building cogeneration power plants (possibly coupled with district heating) for a total electrical and thermal size of 4450 kW_e and 5400 kW_t, respectively.

3. Methods

3.1. The reference energy system (RES)

In this study users were divided into agriculture, industry, households, services and transport. Agriculture was then excluded from the model because of its negligible share of municipal energy consumption (Table 2). On the contrary, industry is a very large user. Pesaro's industrial sector is highly diversified both in terms of goods produced (e.g. pleasure craft, furniture, and bricks) and of manufacturer sizes, which range from large factories to small and medium-sized enterprises (SME). The study considered industry as a whole and projected it up to 2030 based on a general driver, "GDP trend" (Terna, 2008). Table 6 shows the GDP projection for the study period, which does not take into account the financial and economic downturn that has been affecting Italy since 2009.

Similarly, marketable services were also projected according to GDP and considered as a whole, since their broad range makes it difficult to identify a set of current or future technologies.

Households, public services, and private and public transport were analysed in detail. The study design required accounting for the seasonal increase in energy consumption related to summer tourism. Tourists, who in 2001–2004 accounted for ca. 11% of residents (Pesaro Municipality, 2005), were however entered only for the household sector. Table 7 shows the price of the energy commodities considered in this study. The 2004 and 2010 prices are actual market prices (Appendix A); 2030 price projections were according to IEA (IEA, 2006, 2007).

3.2. Energy demand by sector

In the following paragraphs the main quantitative data are presented for each sector modelled in the study. Growth of the demand for energy commodities depends closely on the trends of the relevant drivers. Nevertheless, a number of drivers, rather

than a single one, usually affect demand. In this work demand evolution was considered to be related to a single main driver. Additional qualitative information is presented in Appendix B.

3.2.1. Households

The main driver chosen for this sector was "population", sometimes combined with "total built area". Base year population data were obtained from official statistics (ISTAT). For population projections, statistical bodies provide three levels of estimates (low, medium, and high): we used the intermediate data. "Total built area" was available only for the base year. However, since projection of the thermal energy demand to 2030 requires entering the rate of construction of new buildings, a rate of 0.8% was assumed, in line with the REEP. The demand related to appliances was calculated on the basis of Italian studies (Cesi, 2005a,b) providing market penetration estimates up to 2030. The overall energy service demand by the household sector rose by 11% between 2005 and 2030.

The thermal energy consumption of households is closely related to building energy efficiency, which has recently been regulated in Italy. The energy demand for space heating was assumed to be 105 kWh/sqm/year for buildings erected after 2006; 80 kWh/sqm/year for those built after 2009, and 60 kWh/sqm/year for those built after 2016. The average specific thermal energy demand related to buildings erected before 2006, calculated during the calibration phase, was 150 kWh/sqm/year. The combination of new building construction and building energy efficiency targets was implemented in the model as household thermal energy demand input, which in 2030 is 13.3% lower than in the reference year.

3.2.2. Public services

Since the work was carried out in collaboration with a municipality, the study models the strictly municipal services, i.e. schools (for the first 8 years of education), municipal lighting (streets, cemeteries, and traffic lights), and municipal offices. Theatres, sports facilities (both municipal), secondary schools and lighting of provincial roads (both provincial) are not modelled separately, but are included in the service sector. The main driver used to project the energy demands of interest for the PS was "population". The demand for thermal energy, i.e. for heating and cooling municipal buildings (offices and schools), was assumed to be constant, since the 0.8% growth in annual demand entered for the household sector seemed implausible. The decision was supported by the absence of plans for construction of new public buildings. Finally, the growth rate of the demand for public

Table 6
Trend of GDP growth.

YEAR	2000–2005	2005–2006	2006–2007	2007–2012	2012–2018	2018–2030
Average GDP annual growth (%)	0.9	1.8	1.5	0.6	1.7	1.2

Table 7
Energy commodity prices.

	2004			2010			2030		
	Households	Services	Transport	Households	Services	Transport	Households	Services	Transport
Electricity (€/kWh)	0.17	0.15		0.168	0.148		0.24	0.211	
Natural gas (€/Nmc)	0.582	0.532	0.767	0.582	0.532	0.943	1.697	1.552	2.527
Unleaded petrol (€/l)			1.221			1.450			2.680
Diesel (€/l)			1.109			1.352			2.976
Lpg (€/l)			0.567			0.659			1.036

Table 8
Synoptic summary of implemented policies in the three scenarios modelled.

Sector	BAU scenario	EPS scenario		EM Scenario				
	Households, holiday homes, municipal buildings, public lighting, transport	Households, holiday homes, public lighting, transport	Municipal buildings	Public lighting, Transport	Municipal buildings	Households	Holiday homes	
<i>Policy constraints/targets</i>								
Building energy efficiency targets	Existing residential buildings: 150 kWh/sqm/year	Existing household buildings: 150 kWh/sqm/year	120 kWh/sqm/year by 2030	–		Energy demand for space heating: 120 kWh/sqm/year by 2030	Existing residential buildings: 150 kWh/sqm/year	–
	New residential buildings: 105 kWh/sqm/year (from 2006)	New households buildings: 105 kWh/sqm/year(from 2006)					New residential buildings: 105 kWh/sqm/year (from 2006)	
	80 kWh/sqm/year (from 2009)	80 kWh/sqm/year (from 2009)					80 kWh/sqm/year (from 2009)	
	60 kWh/sqm/year (from 2016)	60 kWh/sqm/year (from 2016)					60 kWh/sqm/year (from 2016)	
	Existing municipal buildings (mainly schools and offices): 175 kWh/sqm/year in 2004 130 kWh/sqm/year by 2030							
PV systems^a	Solar feed-in tariff mechanism (<i>Conto Energia</i>), in force since 2005	Solar feed-in tariff mechanism (<i>Conto Energia</i>) in force since 2005	Must account for 20% of PS electrical energy consumption by 2030	–		Must account for 20% of PS electrical energy consumption by 2030	Energy production must account for 10% of electricity consumption by 2030	Energy production accounting for 5% of electrical energy consumption by 2030
Micro-chp plants^b	Minimum cost criterion	Minimum cost criterion	Total thermal energy produced by new technologies must account for 20% of the thermal energy consumed by the PS in 2030: • 10% by micro-turbines or ICE; • 10% by Stirling engines or FC	–		Total thermal energy produced by new technologies must account for 20% of the thermal energy consumed by the PS in 2030: • 10% by micro-turbines or ICE; • 10% by Stirling engines or FC	Total thermal energy production must account for 20% of the thermal energy consumed by households sector in 2030: • 5% by micro-turbines or ICE; • 15% by Stirling engines or FC	–
Solar thermal plants	Minimum cost criterion	Minimum cost criterion	–	–	–		Energy production must account for 10% of thermal energy consumption for hot water by 2030	Energy production must account for 20% of thermal energy consumption for hot water by 2030
Other	Minimum cost criterion for public lighting, transport, electrical and thermal devices in households, and PS	Minimum cost criterion for public lighting, transport	Minimum cost criterion for public lighting, transport, electrical and thermal devices in households sector	Minimum cost criterion for Public lighting, Transport	Minimum cost criterion for Electrical and thermal devices in PS	Minimum cost criterion for Electrical and thermal devices in PS	Minimum cost criterion for Electrical and thermal devices in households	Minimum cost criterion for Electrical and thermal devices in households

^a PV systems are modelled for self-production of final users, not as energy sources. Consequently their market penetration will result in lower electrical energy consumption.

^b All micro-chp technologies have PES index > 0 and global efficiency=75%. Note: ICE: internal combustion engine; FC: fuel cell; PES: primary energy saving.

lighting, was assumed to be 0.8% a year, based on the REEP. For the BAU scenario, we assumed a PS thermal energy demand of 130 kWh/sqm/year in 2030, in relation to the targets set by current regional policies. Since the demand for thermal energy was assumed to be constant, the building energy efficiency targets were implemented by assuming a yearly linear decrease in the thermal energy demand. In particular, the reduction of thermal energy demand input for municipal offices and schools in 2030 was 24.5% compared to the reference year.

3.2.3. Transport

The transport of goods was ascribed to industry and marketable services, and projected based on GDP. The energy demand for passenger transport was divided into public (buses) and private (cars) and projected on the basis of “population”. Actually, the main drivers used to model passenger transport were “passenger/km” for public transport and “passenger/vehicle” for private transport, where “passengers” were projected according to population trend. This decision was due to the fact that Pesaro municipality has no studies (e.g. the “Urban mobility plan” (Pesaro Municipality, 2003)) providing projections for passenger/vehicle or passenger/km until 2030. Therefore the energy service demand by the private transport sector increased by 21.06% in 2030.

3.3. Technology database

The technology database of the electrical and thermal devices entered in the model makes reference to existing studies for Italy (Cesi, 2005a,b; Confindustria, 2006) and to documents published by manufacturers associations (CECED Italia, 2005). The transport database includes all vehicle categories (cars, buses, and commercial vehicles), sizes, fuel types, emission categories (e.g. pre-Euro, Euro I, and Euro II), and specific consumption. The micro-combined heat and power (micro-chp) technology database takes into account electrical and thermal efficiencies as well as capital and maintenance costs (Bartolini et al., 2006, 2007; Caresana et al., 2010, 2011a). It is worth noting that the total efficiency of micro-chp systems can be maximized by giving priority to thermal load and self-consumption of the electrical energy produced (Caresana et al., 2010, 2011a), for such reason, these systems were modelled as boilers, whose electricity production was subtracted from the energy consumption of the sector.

3.4. Scenario assumptions

The aim of the study was to develop three energy scenarios for the city of Pesaro, as follows:

- Business as usual (BAU);
- Exemplary Public Sector (EPS); and
- Exemplary Municipality (EM).

3.4.1. Business as usual scenario (BAU)

The BAU scenario is a reference scenario, in which the model optimizes future consumptions and technologies according to minimum cost criteria, without considering any specific policies that are not already in force, being introduced, or scheduled to be enacted. This scenario merely optimizes (i.e. minimizes) the total costs of all systems.

3.4.2. Exemplary public sector (EPS)

According to art. 5 of Directive 2006/32/EC (European Parliament and Council, 2006), the PS should play an exemplary

role in the energy sector. Furthermore “Member States shall ensure that energy efficiency improvement measures are taken by the public sector (...) at the appropriate national, regional and/or local level”. Such role is literally exemplary, given the small fraction of consumption accounted for by the PS (1%) compared with the whole municipality. The goal of the EPS scenario is precisely to assess potential local PS energy policies and their effectiveness in the medium-long term in order to enact its exemplary role. The EPS scenario shows the potential effects on energy consumption of the adoption of a virtuous energy policy by the (municipal) PS. The main constraints introduced were a greater energy efficiency of public buildings, the adoption of energy efficiency measures and the installation of new (or relatively new) technologies, such as micro-chp systems and PV solar panels, in public buildings. Solar thermal plants were not considered due to the low energy demand for hot water in public offices and schools. The building energy efficiency targets were implemented by assuming a yearly linear decrease in the thermal energy demand input. In particular, the reduction of thermal energy demand input for municipal offices and schools in 2030 was 29.2% compared to the reference year.

3.4.3. Exemplary municipality (EM)

In the EM scenario the main actions modelled in the EPS scenario are hypothesized to be extended to the household sector, with slight adjustments related to different demand characteristics; for instance, the greater demand for hot water by households entails a greater diffusion of technologies such as solar thermal, especially in holiday homes. Micro-chp systems are not considered for holiday homes, because the low demand for hot water and, especially, space heating, makes them unprofitable. Table 8 provides a synoptic view of the policies and targets entered for each scenario.

4. Results analysis

The main result of scenario analysis is not an absolute value, but rather differences between the trends of different scenarios, which allow evaluation of policy effectiveness (or of new technologies installed). In this work the BAU scenario, which includes no local policy or constraint other than current or soon-to-be-adopted national policies, is the reference scenario. The other two scenarios, EPS and EM, model the effectiveness of the constraints (local policies) entered (Table 8), allowing comparisons to the BAU both in terms of energy consumption and of economic performance.

4.1. BAU scenario

The BAU scenario does not involve a projection or tendency, but is a result in itself, since the model optimizes future consumptions and technologies according to minimum cost criteria.

Energy consumption in the municipality is illustrated by sector in Fig. 1, which shows that, compared to the base year, it:

- increases considerably in the service (+20%) and industry (+31%) sectors throughout the study period;
- declines in the household sector (−23%);
- falls in the short term (−22% in 2015) in the transport sector then eventually rises, albeit not returning to initial levels (−14% in 2030); and
- decreases in the short term (−2.5% in 2015) for the town overall but then increases in the longer term (+5.9% in 2030).

The general upward tendency of energy consumption depends on the inclusion in the model of industry and marketable services,

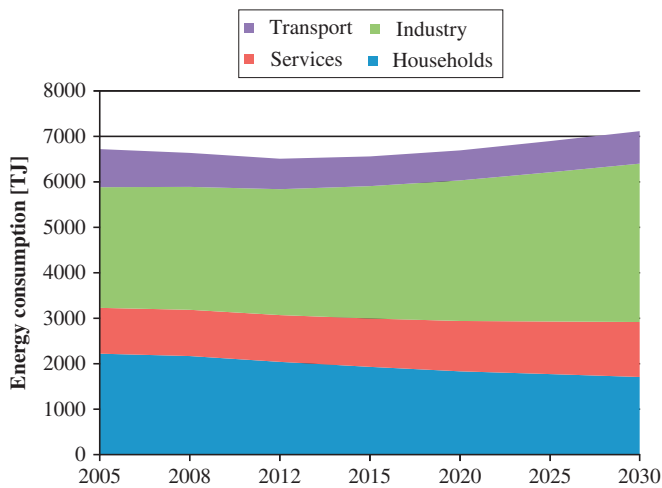


Fig. 1. Pesaro's overall energy consumption according to the BAU scenario.

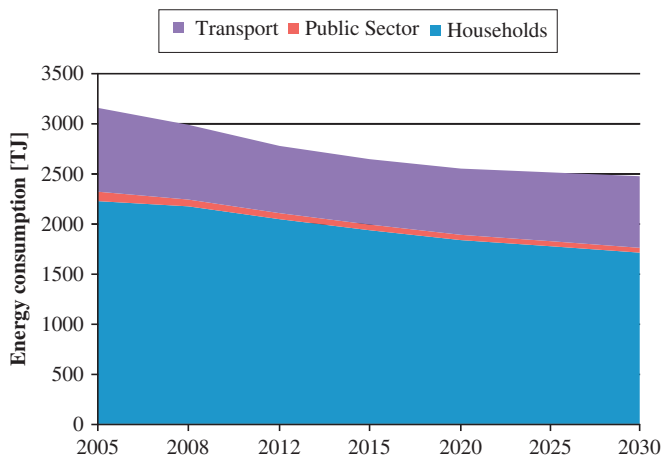


Fig. 2. Energy consumption curves of the three sectors modelled.

which account for > 50% of the whole energy demand and are projected according to GDP, which is assumed to grow throughout the period. The short-term decline is the result of the combination of thermal energy demand targets (greater building efficiency) and scenario optimization by the TIMES model, since in this timeframe the growth of the demand from these sectors is more than offset by improved energy efficiency in the sector modelled. This effect wanes in the medium term (after 2020) as a result of the replacement of existing technologies with marginally more efficient ones. In particular, due to the inputs entered in the model, replacement is faster over the first 15–20 years of the scenario, leading to market saturation for some technologies in its final period (as for instance in the case of private transport, Fig. 6). In practice, the model exploits all the potential of the database of some technologies before the end of the scenario in 2030.

Fig. 2 illustrates how improvements in energy efficiency can reduce the energy demand in the sectors modelled, attenuating the rise of overall energy demand, which based on GDP projections alone would be much steeper. In particular, compared with the base year, in 2030 the energy consumption of households, PS and transport is 23%, 30%, and 14% lower, respectively.

4.1.1. Households

Analysis of household energy consumption in the BAU shows a reduction of 23% compared to the base year. Figs. 3 and 4 show that consumption of thermal and electrical energy by holiday homes is

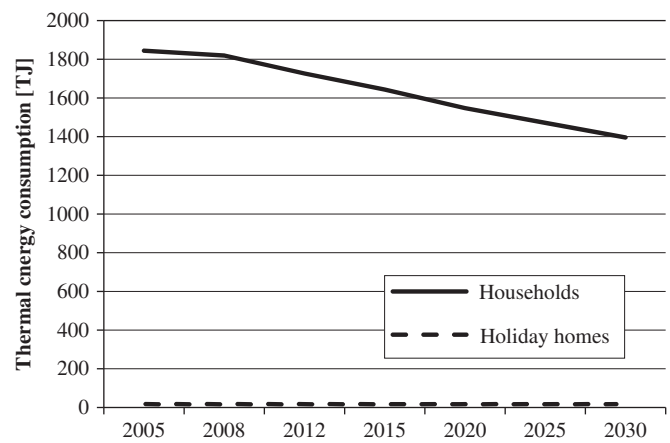


Fig. 3. Thermal energy consumption by households.

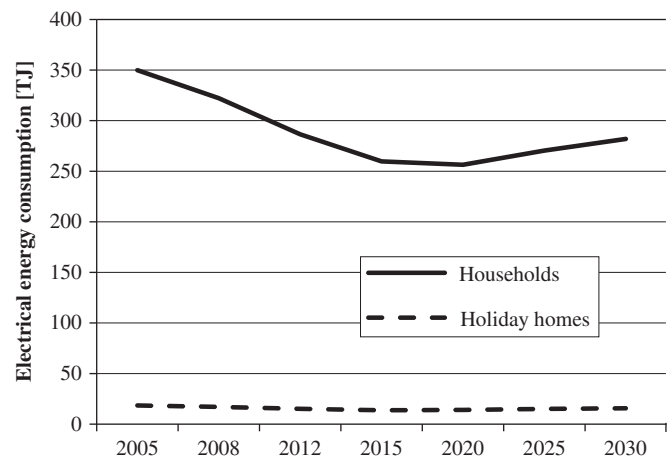


Fig. 4. Electrical energy consumption by households.

Table 9

Production of solar thermal energy for water heating in holiday homes in the BAU scenario (Tj).

	2005	2008	2012	2015	2020	2025	2030
BAU	0	0.06	0.11	0.17	0.34	0.68	1.36

negligible compared with households, accounting respectively for < 1% and 7% of the annual demand in the base year. Energy consumption by households is predominantly thermal and decreases over the years; this is more evident in 2030, when the reduction depends both on the increase in building energy efficiency and on the market penetration of new technologies (e.g. heat pumps). Household electricity consumption declines until 2020 (–26.6%), then rises because of technology saturation and the growing penetration of electrical heat pumps (in 2030: –19.2% compared to the base year, +10% compared with 2020).

As regards renewable energy production, it should be noted that solar thermal panels enter the market despite the absence of incentives, demonstrating the technology's inherent profitability (Table 9).

4.1.2. Public sector

In the BAU scenario PS energy consumption declines to a level that in 2030 is 29.7% lower than in the base year (Fig. 5). Initially

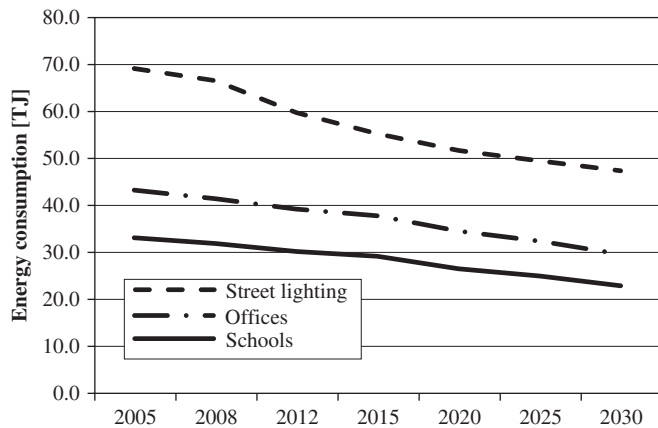


Fig. 5. Municipal energy consumption according to the BAU scenario.

the reduction is the result of the combination of thermal energy demand targets (greater building efficiency) and the rapid effect of the replacement of older lighting technologies with newer and more efficient ones (electrical energy reduction). After this effect has faded, due to market saturation, and electrical energy consumption has steadied, the continuing declining trend until 2030 can be explained with the further substitution of boilers (thermal energy reduction), whose replacement rate is slower than that of lighting technologies.

4.1.3. Transport

The model of the transport sector constructed for the BAU scenario was also applied to the other two scenarios, because the study does not aim to evaluate the result of future policies in this sector (which would require a specific study), but only to project future consumption trends and the shares of technologies and fuels according to minimum cost criteria. Fig. 6 depicts the share of each fuel type. The overall trend depends predominantly on private sector demand for unleaded petrol, which accounts for about 75%, followed by diesel fuel. Fig. 6 also shows that while consumption of unleaded petrol reaches a minimum around 2015, the share of diesel fuel declines until 2030, a trend that can be explained by rising prices (Table 7). Although the shares of Lpg and natural gas increase, they account for a small proportion of overall consumption.

Fig. 7, reporting the consumption of unleaded petrol divided by EU emission standards (European Parliament and Council, 2001), illustrates the progressive replacement of the more polluting and energy-inefficient vehicles (Euros 1–2 and 3–4) by more efficient models. In 2030 technology saturation has taken place. Finally, Fig. 8 depicts the trend of energy consumption by public transport means. This trend is due to a combination of growing population, which is the demand driver, and the increasing fuel efficiency of new buses, replacing the oldest ones at their end of life. Total energy consumption grows with the population and plateaus after 2012, since increasing fuel efficiency offsets the population increase.

4.2. EPS scenario

The PS energy consumption in the EPS scenario shows a decreasing trend up to 2030. Nevertheless, comparison with the BAU (reference) scenario suggests two considerations. Firstly, the EPS, like the BAU scenario, involves an initial reduction of consumption as a result of thermal energy demand targets (greater building efficiency) and the rapid effect of the replacement of older lighting technologies (traffic lights and cemetery)

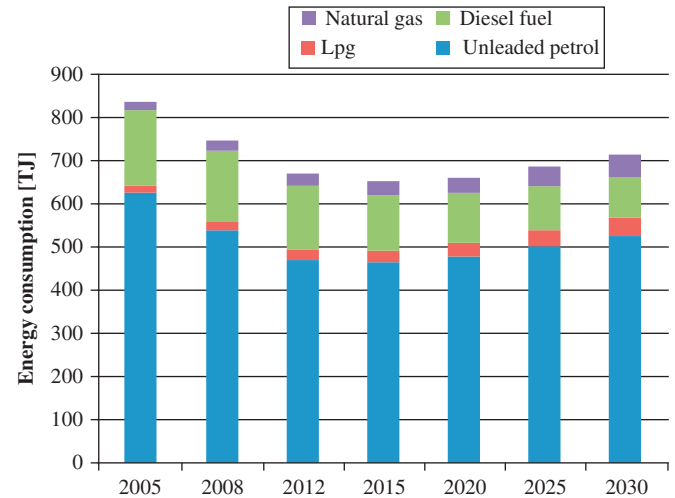


Fig. 6. Total annual energy consumption by the transport sector, by fuel type.

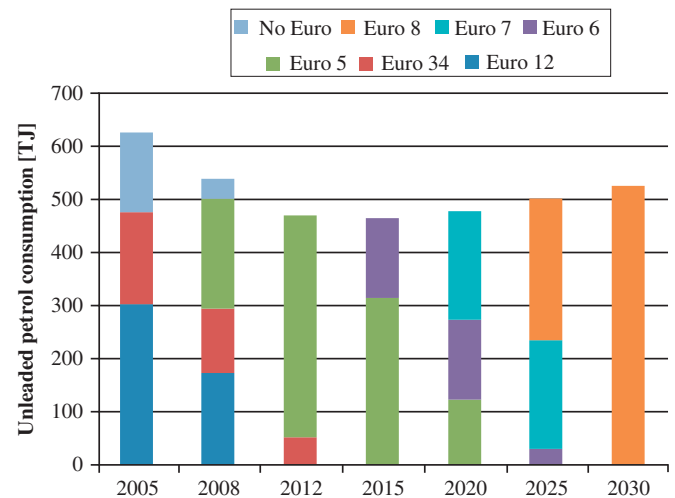


Fig. 7. Share of the energy consumed by petrol vehicles.

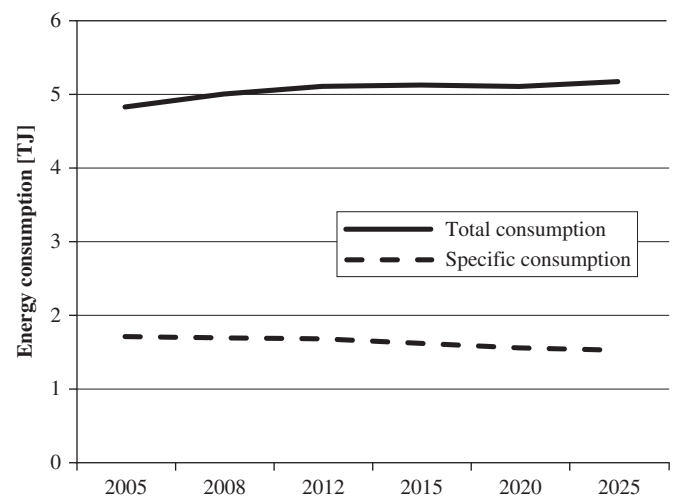


Fig. 8. Total and specific energy consumed by public buses.

with newer and more efficient ones lighting (–32% in 2030). Secondly, in the EPS scenario overall energy consumption decreases by 27.8% in 2030 compared with the base year

(Fig. 9); the decrease is smaller than the 29.7% seen in the BAU scenario.

Comparison of Fig. 5 (BAU) and 9 (EPS) shows quite similar short-term energy consumption trends in the two scenarios, with a divergence only after 2020 due to the diffusion of PV and, especially, micro-chp systems. In fact, micro-cogeneration has two effects: on the one hand it reduces electrical energy consumption through self-production of electricity, and on the other it increases primary energy consumption through the use of fuel to feed the prime mover. The final effect is an overall reduction of primary energy consumption which is usually calculated by the PES (primary energy saving) index. From the energy point of view, the PES index quantifies the amount of primary energy that can be saved by heat and power cogeneration compared with separate generation (Caresana et al., 2010b).

Therefore, selection of a $PES > 0$ (Table 8) entails overall savings of primary energy compared both with electricity production in a centralised power plant and with production of thermal energy with traditional boilers. Since the city of Pesaro imports electrical energy from plants located outside its boundaries, installation of micro-chp

systems entails internalization of part of the energy produced, i.e. part of the energy which in the BAU scenario is produced outside the municipality is produced within the town boundaries in the EPS. Therefore, electricity consumption being equal, the adoption of micro-chp systems entails that part of the primary energy commodities (i.e. fuel to feed the cogenerators) is consumed in the municipality. The result is that in 2030 local consumption is 2.8% higher in the EPS than in the BAU scenario.

4.3. EM scenario

Analysis of household energy consumption in the BAU and the EM scenarios (Fig. 10) shows a reduction of 23% and of 21%, respectively, compared with the base year. As in the EPS scenario, the adoption of distributed micro-chp systems entails internalization of some energy consumption, since part of the electrical energy, previously imported from outside the municipality, is now self-produced, entailing a greater internal use of primary energy (+3.7% compared with the BAU, in 2030). Despite this, the constraint of a $PES > 0$ (Table 8) for micro-chp technologies means that the overall primary energy consumption is lower than in the BAU scenario, in line with REEP targets.

With reference to micro-chp systems, only micro-turbines and Stirling engines are selected by the model for installation in households in the course of the study period. They spread by virtue of their greater thermal efficiencies compared with internal combustion engines (ICE) and fuel cells (FC), respectively, since the 20% target of thermal energy produced by micro-chp systems is achieved with a smaller number of devices. Table 10 shows the electrical energy produced by new technologies throughout the period.

These data indicate that micro-chp systems have a large potential role in increasing the share of home-produced electrical energy. In fact the projections clearly show that by 2020 micro-chp electricity production could overtake production by PV plants, a technology now available on the market.

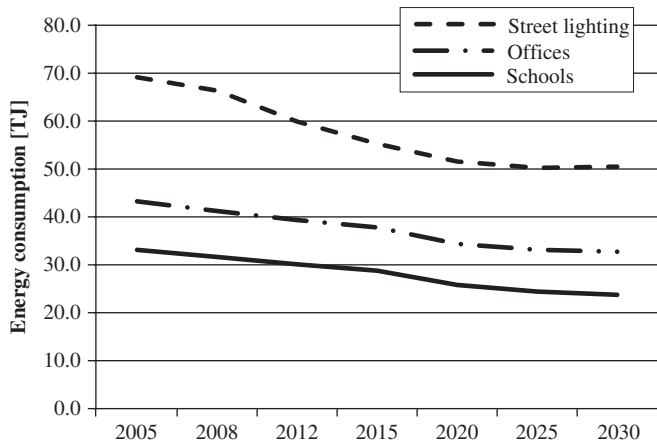


Fig. 9. Municipal energy consumption according to the EPS scenario.

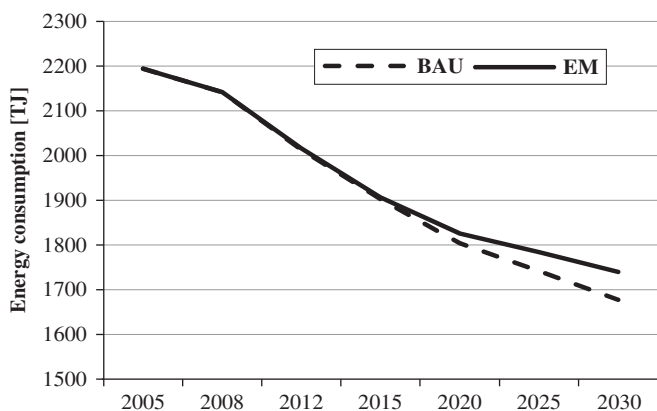


Fig. 10. Energy consumed by households in the BAU and EM scenarios.

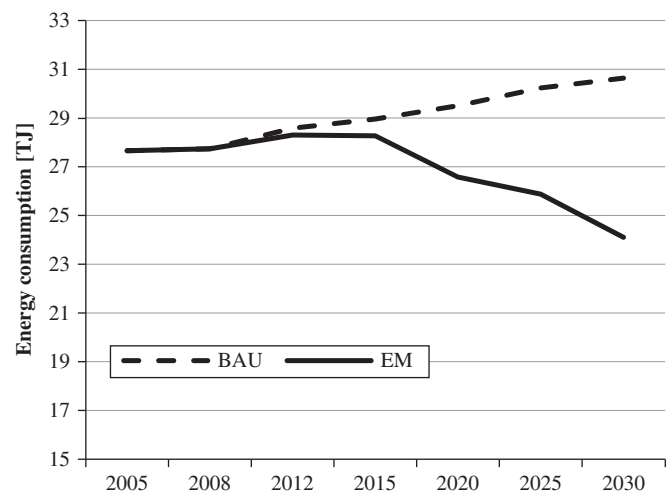


Fig. 11. Energy consumed by holiday homes in the BAU and the EM scenarios.

Table 10
Electricity produced by new technologies (TJ).

	2005	2008	2012	2015	2020	2025	2030
Stirling engines	0	0	0.04	4.28	10.98	21.33	30.84
Micro-turbines	0	0	0.13	5.05	12.84	21.97	30.36
PV systems	0	0	8.49	14.41	23.93	35.70	48.13
Proportion of total electricity consumption (%)	0	0	2.02	5.79	12.03	19.11	25.40

Table 11

Production of solar thermal energy for water heating in holiday homes in the EM scenario.

	2005	2008	2012	2015	2020	2025	2030
Solar thermal energy (TJ)	0	0.06	0.21	0.51	2.31	3.72	5.99
Proportion of total energy consumed for water heating (%)	0.0	0.7	2.0	4.9	22.9	37.2	61.4

Table 12

Synopsis of energy consumption and renewable energy production in the three scenarios.

	2004	2030		
	Base year	BAU	EPS	EM
Energy consumption (TJ)	3108.4	2479.0	2480.6	2512.2
Transport	841.0	719.3	719.3	719.3
Public sector	73.2	51.5	52.8	52.8
Households	2194.2	1708.1	1708.1	1739.7
Primary energy consumption avoided outside municipal boundaries thanks to micro-chp (TJ)	–	–	4.1	151.4
Energy produced with micro-chp and renewable (PV and thermal) systems (TJ)	–	9.5	17.0	370.6

On the contrary, energy consumption by holiday homes is lower in the EM compared with the BAU scenario, as clearly illustrated in Fig. 11, due both to the different degree of penetration of plants producing energy from renewable sources (e.g. solar thermal plants) and to the absence of the internalization effect induced by micro-chp plants. In particular, energy consumption compared with the base year decreases by 15% in the EM scenario and increases by 6% in the BAU scenario. It is worth noting that solar thermal plants are the most profitable renewable energy technology for holiday homes, thanks both to the low initial cost and the high use factor. As shown in Table 9 this technology enters the market already in the BAU scenario, but is widespread in the EM scenario too, thus considerably reducing energy consumption (Table 11).

Table 11 shows the solar thermal energy generated for hot water production throughout the period.

The energy consumption estimated for the three scenarios is summarized in Table 12, which also reports separate figures for the energy produced by micro-chp and renewable technologies and for the primary energy not consumed by plants outside the municipal boundaries thanks to micro-chp plants. In particular, the table clearly highlights that the EPS and EM scenarios improve on the BAU performances. In fact, if the primary energy consumption avoided via micro-chp systems is added, the BAU energy consumption is higher compared with both the other scenarios. The difference would have been even greater if more efficient micro-chp technologies (ICE and FC) had entered the market.

4.4. Cost of policy implementation

The results of scenario analysis must be examined both in terms of energy consumption/production (reduction of energy consumption, share of renewables) and of implementation cost, since each policy does entail a cost. TIMES is a useful tool to support decision-making in this setting. The above local scale analysis also provides an order of magnitude of policy costs. The three scenarios were modelled and analysed to estimate the effects of the introduction of new technologies and of the adoption of energy policy decisions. However, the gains entailed by policies never come at no expense: in fact, the cost of each scenario is the cost of the policies it involves. In our study the cost differences between the EPS and the BAU scenario are therefore related to the PS policies implemented by the municipality, whereas the differences between the EM and the EPS scenario

Table 13

Cost difference of the three scenarios (M€).

	BAU	EPS	EM
BAU	0	–210	–501
EPS	210	0	–291
EM	501	291	0

are related to the cost of extending the same policies to households. Table 13 shows, over the period of the model, the cost of the policies implemented in the EM and EPS scenarios compared with the BAU scenario, taken as the reference, whose cost was estimated to be 36 730 M€. The cost of implementing the policies to boost household PV use throughout the period was calculated to be 32.68 M€, including capital and maintenance costs.

5. Discussion

Analysis of the results, presented in the paragraphs above, suggests a number of considerations.

- The first regards the strategic role of final user energy efficiency in curbing energy consumption; in particular, the technologies characterized by high efficiency and low cost (i.e. lamps) are the ones best meeting the least-cost criterion applied in the TIMES model.
- The EPS and EM scenarios showed that policies promoting the diffusion of solar technologies, both thermal and PV, reduce municipal energy consumption, whereas those promoting the adoption of micro-chp systems entail greater energy consumption at the local level, because part of the electricity consumed is no longer imported, as in the BAU scenario, but is self-produced. Anyway, as mentioned above, micro-chp technologies (with PES > 0) entail an overall reduction of primary energy consumption. We feel this point should be stressed, because distributed generation, i.e. energy production right where it is consumed, gives local communities a sense of responsibility in the energy sector.
- Policy implementation in the EPS and EM scenarios involves considerable costs, shown in Table 13. According to our estimates the cost of 210 M€ over 25 years (~8.4 M€/year) is quite high for the municipal coffers; however, thoroughly planned third-party capital financing mechanisms involving

municipality, Energy Service Companies (ESCO) and financial backers could help meet it (Brown, 1993; Vine, 2005; Okay et al., 2010; Marino et al., 2011).

The 291 M€ required to extend the EPS scenario policies to the household sector is clearly much harder to sustain, due both to the difficulties in extending third-party financing mechanisms to this sector and to the huge number of final users. Nevertheless, considering that Pesaro's household sector consists of 30 000 homes, 291 M€ over 25 years translates into about 388 €/year/dwelling. The sum includes the cost of PV technology incentives (about 44 €/year/dwelling); part of the remaining 344 €/year/dwelling could be obtained through a reduction of natural gas tax.

- (iv) Since the model's output crucially depends on its inputs, including modeller sensitivity, these aspects deserve further consideration. For a credible analysis, input data need to be taken as far as possible from reliable sources, such as nationwide or sectoral official studies (Appendix A). The TIMES model generator optimizes the supply of energy services at minimum overall cost. Since this approach differs significantly from the reasoning both of private citizens and of public authorities, its results require careful assessment and interpretation. For this reason, policy evaluation requires exhaustive knowledge of the scale investigated besides the assumptions that govern the modelling of complex systems.
- (v) Finally, during the data collection stage we became aware that citizens and, especially, public bodies are not very interested in collecting energy consumption data. This results in suboptimal energy management. It is worth noting that monitoring these data is itself an energy-saving activity, since it promotes end-user awareness, thus reducing consumption.

5.1. Considerations on the use of the TIMES model generator on the local scale

Use of the TIMES model generator to develop municipal-scale scenarios showed pros and cons that are partly ascribable to the small scale of the system modelled. Analysis of such scenarios is usually beset by a number of problems connected to the absence of systematic data collections. The smallest scale of systematic collection of electricity data in Italy is the provincial scale, while disaggregated statistics for natural gas are not available even on this scale. The same applies to vehicle fuel. To meet the problem of collection, most data were obtained, with the help of the municipality, directly from local utilities, who were at the first unwilling to disclose them due to their sensitivity in an open market context (Appendix A). These limitations and difficulties resulted in significant modifications to the original RES (which initially also included industry and services), as it required a number of data that eventually proved to be unavailable.

TIMES proved to be a suitable and valuable tool to describe municipal-scale energy demand and the effects of the adoption of local energy policies on the final consumption of the sectors modelled. In our opinion, calibration of the base year provided a more realistic and reliable description of the energy demand of the different sectors than is feasible on a larger scale. A case in point was the modelling of seasonal phenomena, like the influence of tourists on the energy demand by households; in a larger-scale model, their contribution would have been concealed or blurred. Furthermore, the MarkAL-TIMES methodology requires the modeller to investigate future energy technologies, in particular those that best fit local conditions, thus adopting a new approach to the evaluation of scenario results. In fact, the thorough knowledge of the territory by local policymakers allows

going beyond traditional cost–benefit analysis, which though useful in large-scale assessments of technologies and policies may entail smoothing or effacement of (often large) differences between areas by the simplification required by the model itself. An additional benefit of the MarkAL-TIMES is that local-scale scenario analysis can be verified directly year by year. Special caution is required when using the TIMES to model a small-scale system compared with a larger-scale one. In fact, MarkAL-TIMES is an equilibrium model that assumes competitive markets for all commodities, a hypothesis that does not really apply to the local scale, since the smaller the system the less the market competition. At this level the energy demand, though affected by exogenous parameters, has no effect on the price of the main factors driving local customers, because commodity prices and the cost of technologies are the result of national demand and supply equilibria, which are not influenced by local behaviours. The local system is therefore strongly dependent on parameters external to its boundaries, requiring their careful selection by the modeller: commodity prices are entered as boundary conditions and are not the result of an optimization process; for instance, in this work electricity prices do not reflect the cost of production by an optimized mix of technologies. However, the problem of the influence of external parameters is limited here by the fact that most such factors, such as energy commodity prices, are continuously monitored; therefore official data, statistics and reliable projections are readily available. On the contrary, a study addressing the best conditions for the market entry of particular technologies would probably benefit from sensitivity analysis with regard to exogenous factors, such as commodity prices.

Nevertheless, none of the above considerations undermine the ability of TIMES to develop scenarios and to evaluate the effectiveness of local-scale energy policies, in particular in terms of energy demand. They simply highlight the need for choosing carefully both the boundary conditions of the model and the sectors to be analysed. In fact, we feel that the small extension of the present system allowed developing meaningful scenarios only for the sectors that can easily be analysed in detail, such as the PS, households and transport. Industry and other service sector activities, which clearly are not managed at the municipal level, were reported as aggregates based on published GDP estimates, since disaggregated data were not available. However, the scarce or no effect of local policies on such sectors reduces the impact of this limitation. Further limitations of the work are related to the extent of simplification applied and to the scenario timeline. In fact, although the energy demand depends on multiple factors (e.g. GDP, population, economic situation, and habits), “population” was entered as the main driver, due to the availability of medium-long term official forecasts on a local scale.

6. Conclusions

This work presents three medium/long-term energy scenarios for Pesaro, a seaside town in central Italy. Its aim was to provide local decision-makers with information about the effectiveness and cost of a number of energy policies, so that the value of implementing them on a local scale can be assessed. Three sectors were analysed in depth: PS, households and transport; in particular, since the town's energy consumption is affected by strong tourist flows, holiday homes were also considered. The scenarios were as follows: Business as Usual (BAU), Exemplary Public Sector (EPS), and Exemplary Municipality (EM). The first scenario optimizes future consumptions and technologies according to minimum cost criteria, without considering any specific policies that are not already in force, being introduced, or scheduled to be enacted. The EPS and EM scenarios consider energy efficiency and

technology penetration targets respectively for the PS alone and for both the PS and the household sector, respectively. In particular, the former scenario models the exemplary role of local administrations as defined and promoted by recent EU directives. The model showed that the most promising policies in curbing fossil fuel consumption are as follows: (i) replacement of old, inefficient technologies with newer and more efficient ones; (ii) improvement of building energy performances; and (iii) promotion of renewable energy (PV and solar thermal) and micro-chp technologies. The spread of micro-chp systems (micro-turbines, ICE, FC, and Stirling engines) entails both a reduction in overall primary energy consumption and an increase in local energy consumption due to internalization of production of part of the electricity, which was previously imported from outside municipality boundaries.

TIMES proved to be a suitable and valuable tool to describe the energy demand of the community and the effects of the adoption of local energy policies on the final consumption of the sectors modelled. Calibration of the base year provided a more realistic and reliable description of the energy demand of the different sectors than is feasible on a larger scale. A case in point was the modelling of seasonal phenomena, like the influence of tourist flows on household energy demand; in a larger-scale model, their contribution would have been concealed or blurred. Application of the TIMES at the local level requires taking into account a number of parameters external to the system, whose selection is a major challenge for the modeller, since most of them (e.g. commodity prices and the cost of technologies) are usually established by national supply-demand equilibria and are not influenced by local behaviours.

Acknowledgements

The authors wish to thank Mr. Rocco De Miglio for his assistance in data collection and processing, and Silvia Modena for the language review.

Appendix A. Data sources

Data retrieval was possibly the most time-consuming phase of the work, for several reasons: first of all, the absence of data and statistics about energy consumption at lower than the provincial scale; second, but not less important, the fact that all existing data are held by local providers of energy commodities, who are usually unwilling to disclose them because of their market-sensitive nature in a liberalized market for local energy commodities. Furthermore, when available, the data acquired were often not comparable or not disaggregated. Most of the data were obtained, or reconstructed, by crossing tax system data and national statistics. The year for which the broadest database was available was 2004. The main data sources are listed in Table A1.

Appendix B. Reference energy system

B.1. Households

The household sector consumes a significant amount of energy, albeit with a small amount of appliances. National statistics about the diffusion of such appliances as well as valuable studies about future technologies are provided by public and private organizations (Cesi, 2005a,b; Confindustria, 2006; ISTAT; CECED Italia, 2005). Statistical data were analysed to establish the actual consumption of Pesaro's households,

Table A1
Data sources.

Data source	Mined for
Marche region	Regional environmental targets; trends of new residential construction
Local electricity and natural gas providers	Energy consumption in the municipality
Inland Revenue Offices	Fuel sales
ACI (Italian Automobile Club)	Number, size, and registration date of vehicles registered in the municipality
ISTAT, National Statistics Institute	Population and projected increase to 2030; type and construction year of existing buildings
CECED, European Committee of Domestic Equipment Manufacturers	Statistics, efficiency, price, market penetration and diffusion trends of household appliances
CESI	Statistics, efficiency, costs, market penetration and diffusion trend of electrical household appliances
Confindustria (Confederation of Italian Industry)	Statistics, efficiency, costs, market penetration and diffusion trend of electrical and thermal appliances
Local transport companies	Vehicle consumption and distances covered
Municipality	Energy consumption related to public and private transport, public lighting and tourist flows
TERNA, Terna—Rete Elettrica Nazionale SpA majority shareholder of the Italian high-voltage electricity transmission grid (RTN)	National, regional, provincial energy consumption, GDP projections

including the contribution by tourism (holiday homes). Because seasonal statistics for these data are not available, both energy consumption and the share of each technology needed to be reconstructed from tourist flow data, number of holiday homes, second homes, etc. The share of the various technologies was estimated based on the well-established fact that less energy-efficient appliances tend to be installed in such homes.

Energy demand trends depend on several factors that exert varying influences and have different development prospects over time. Furthermore, the variables used as drivers must be easy to project in the future with acceptable accuracy. Table B1 reports the energy demand drivers of the household sector.

This household model can also be applied to analyse energy consumption on a larger scale (e.g. regional, national), since it includes the home appliances most commonly used in developed countries, which are characterised by considerable technology penetration. Since it also takes into account seasonal tourist flows, it is particularly well suited to cities or countries where tourism significantly affects energy consumption by households.

B.2. Service industry

The service sector is especially interesting, because it includes the PS. It is highly diversified, including both marketable and non-marketable services. Marketable services can be divided into small, medium and large-size providers, but in this study they were considered as a whole to simplify the analysis. In contrast, non-marketable services were divided into public municipal and other non municipal (e.g. universities, hospitals); only the former were explored in detail, since one of the goals of the study is to reduce energy consumption by Pesaro's PS, to reduce the energy bill and at the same time set an example for citizens. The public services examined were municipal offices, schools and public lighting (streets, cemeteries and traffic lights). These services are large energy consumption items for the municipality; furthermore, there is wide scope for their detailed analysis and for reducing their consumption. Here the seasonal effect can be

Table B1
Energy demand drivers of the residential sector.

Demand	Unit	Driver(s)
Hot water	Ml/year	Population, litres water/inhabitant
Other thermal uses	Devices/family	Population, residential units
Heating	Heated m ²	Population, families
Refrigerator	Devices/family	Population, residential units, penetration
Freezer	Devices/family	Population, residential units, penetration
Dishwasher	Devices/family	Population, residential units, penetration
Washing machine	Devices/family	Population, residential units, penetration
Air conditioning	Cooled m ²	Population, residential units, penetration
Other electrical uses	kWh/year	Population, residential units
Lighting	Mlumen/year	m ²
Entertainment	kWh/year	CESI projection

Table B2
Energy demand drivers of the service industry.

Demand	Unit	Driver(s)
Hot water	Mlitres/year	Litres water/user
Other thermal uses	Heated m ²	Heated m ²
Other electrical uses	kWh/year	Population
Air conditioning	Cooled m ²	Cooled m ²
Lighting	Mlumen/year	m ²
Public lighting	Mlumen/year	Population, built m ³

Table B3
Energy demand drivers of the transport sector.

Demand	Units	Drivers
Natural gas	km passenger; km t	Population, passengers vehicle, annual mileage
Lpg	km passenger	Population, passengers vehicle, annual mileage
Unleaded petrol	km passenger; km t	Population, passengers vehicle, annual mileage
Diesel fuel	km passenger; km t	Population, passengers vehicle, annual mileage

ignored, because the energy demand related to public services is not influenced by tourism. The relevant drivers are indicated in Table B2.

B.3. Transport

Transport accounts for a large amount of the energy demand. The sector was included in the model both because of the large amount of data and statistics found in previous local studies, and because a set of plausible future technologies was available. Transport was divided into public, private and commercial; the latter was excluded since it is generally considered as part of the industrial sector or of marketable services. Two main factors were used for the calculations: fuel sale volume by petrol stations and number of vehicle registrations in the area. Fuel sales were subdivided into sales of unleaded petrol, diesel fuel, Lpg, and natural gas. Vehicle data were divided by vehicle type into cars, buses and commercial (lorries, coaches, etc.), size, fuel type, emission category (e.g. pre-Euro, Euro I, and Euro II), and number of vehicles registered in 2004. The main limitation of this approach is that not all the fuel sold in the area is then consumed locally (commuters, tourists, and marine fuel sold at the harbour); nevertheless previous studies of urban mobility and transport assumed the amount of fuel sold in town and then consumed outside the municipal area to be equal to the amount consumed

locally but purchased elsewhere (Pesaro Municipality, 2005). Consultation with the local administrators allowed refinement of the assumption: 18% of annual fuel sales was ascribed to private and public transport and 82% to commercial transport, tourists, commuters and boats. This led to calculation of total annual energy consumption (expressed in GJ) for private and for public transport, which were entered for model calibration. The demand for fuel and its drivers are indicated in Table B3.

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